Estuarine Water Quality Monitoring and Estuarine Carrying Capacity

Eighth Work Plan, Honduras Research 2 (HR2)

Bartholomew W. Green, David R. Teichert-Coddington, and Claude E. Boyd
Department of Fisheries and Allied Aquacultures
Auburn University, Auburn, USA

Delia Martinez and Eneida Ramírez
Laboratorio De Calidad de Agua
La Lujosa, Choluteca, Honduras

Introduction

A collaborative program was begun in 1993 to monitor water quality in major estuaries supporting the shrimp culture industry in southern Honduras (Teichert-Coddington, 1995). This program combines the time and resources of commercial shrimp farming companies in Honduras, the Government of Honduras, local and international educational institutions, and the PD/A CRSP (Green et al., 1997). The monitoring program is unique in that it has generated long-term, continuous, systematic data on estuarine water quality in a shrimp producing area.

Water quality monitoring continues in most of the 13 original sites and has expanded to 29 sites. The additional monitoring sites are primarily small- to medium-size farms located on estuaries and embayments not previously sampled. Some embayments have little or no history of shrimp farming, so baseline water quality prior to the effects of shrimp farming is being established.

The objectives of the water quality monitoring are to:

1. detect changes in water quality;
2. formulate and validate models to predict future estuarine water quality conditions under various scenarios; and
3. estimate carrying capacity of estuaries based on water quality, farm chemical budgets, and estuarine fluid dynamics.

This report focuses on water quality monitoring; modeling and carrying capacity studies will be completed in the following year.

Methods and Materials

Water samples were taken every one to two weeks from the pump discharge of shrimp farms during high tide. This sample presumably represented an estuarine column sample because the pump intake, located at the bottom of the estuary, created a vortex at the water surface. Samples were put on ice and transported to the laboratory where analyses commenced within six hours of sampling. The Choluteca River was sampled at La Lujosa, which is located downstream from the city of Choluteca and upstream from tidal influence.

Water was analyzed for total settleable solids (APHA, 1985), nitrate-nitrogen (by cadmium column reduction to nitrite) (Parsons et al., 1992), total ammonia-nitrogen (Parsons et al., 1992), filterable reactive phosphate (Grasshoff et al., 1983), chlorophyll *a* (Parsons et al., 1992), total alkalinity (by titration to 4.5 pH endpoint), salinity, and BOD_2. Total nitrogen and total phosphorus were determined by nitrate and phosphate analysis, respectively, after simultaneous persulfate oxidation in a strong base (Grasshoff et al., 1983).

Data collected from June 1996 to June 1997 were tabulated by sampling site. For some of the new sites only limited data is available and these sites

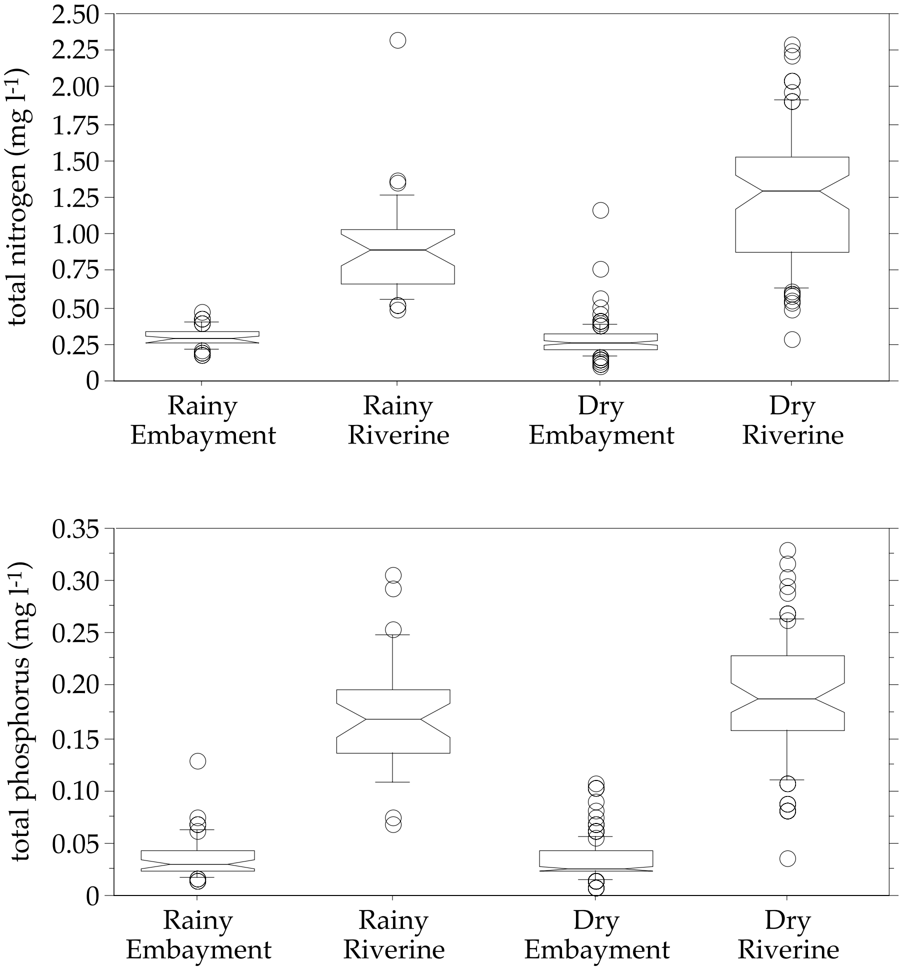


Figure 1. Box plots show comparison of total nitrogen and total phosphorus concentration median values from embayments and a riverine estuary, El Pedregal, from June 1996 to June 1997. Data collected from August through the middle of November (the period of heaviest rainfall) were classified as rainy and all other data were classified as dry. The notches around the median represent 95% confidence limits.

were not included in the results. Comparisons of phosphorus and nitrogen concentrations by inlet type (embayment or riverine) and season were made with box plots. Time-series graphs were made using total nitrogen and total phosphorus concentration data from El Pedregal, a riverine estuary, and data from embayment estuaries sampled from 1993 to 1997.

Results

Data for each site are summarized in Table 1. These results were similar to those reported by Teichert-Coddington (1995). Seasonal rainfall largely determines river estuary water quality. The pattern of rainfall during the wet season is typically bimodal, beginning in May and ending in November with a dry spell during July. Nutrients, particularly nitrogen, concentrate during the dry season when freshwater input is minimal and are diluted with rainwater discharge during the wet season (Figure 1). Water in riverine estuaries is often completely displaced by fresh water during periods of heavy rainfall, as illustrated by the predominance of zero salinities measured in riverine estuaries (Table 1). Embayment water quality varied less with season and was considerably less enriched than riverine estuaries (Figure 1). No trends for long-term nitrogen or phosphorus enrichment were demonstrated in El Pedregal Estuary or embayments during the period of 1993 to 1997 (Figures 2 and 3). Results were similar for the other riverine estuaries.

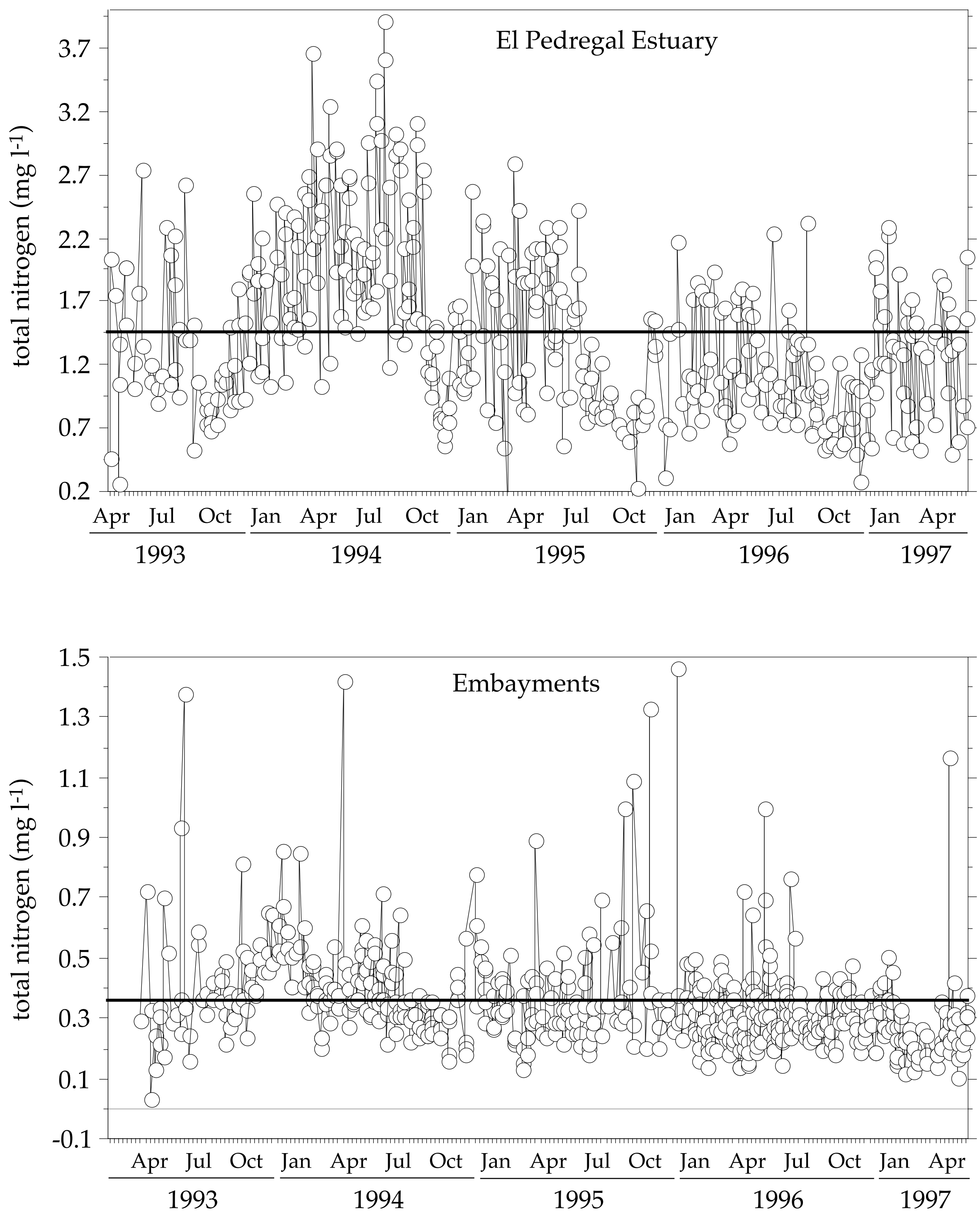
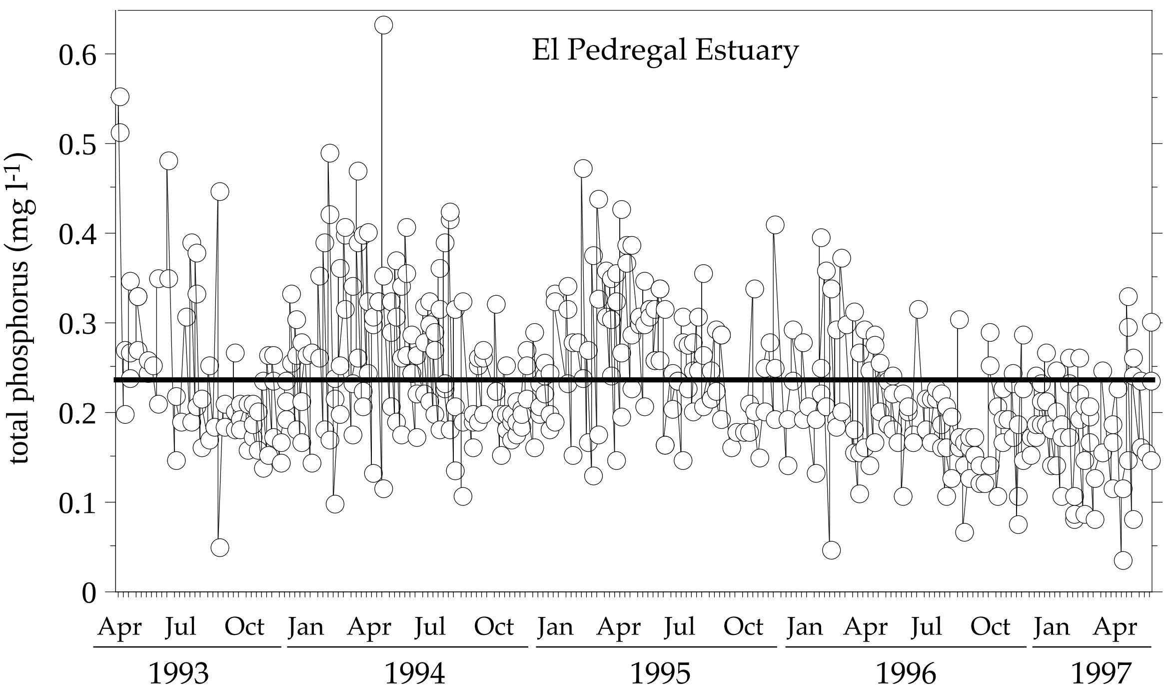


Figure 2. Total nitrogen concentrations are shown from El Pedregal Estuary and embayments of the Gulf of Fonseca from 1993 to 1997. The horizontal line in each graph is the grand mean concentration during this period.



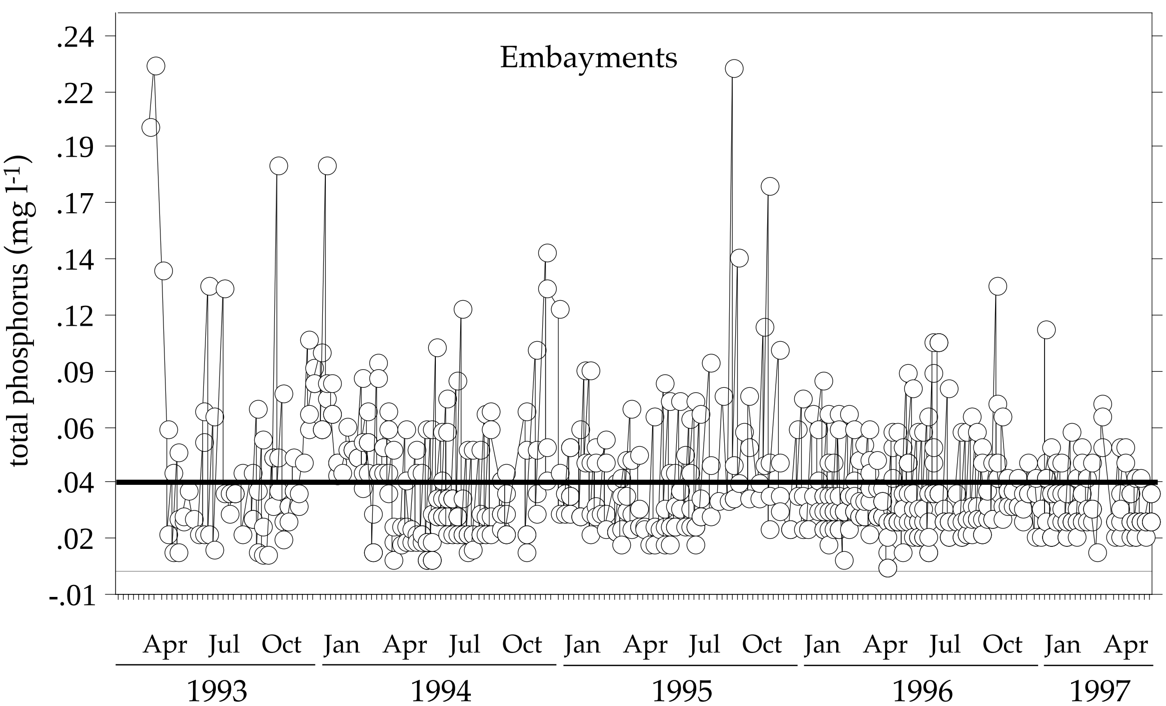


Figure 3. Total phosphorus concentrations are shown from El Pedregal Estuary and embayments of the Gulf of Fonseca from 1993 to 1997. The horizontal line in each graph is the grand mean concentration during this period.

Table 1. Summary of inlet water quality determinations from shrimp farm sites in southern Honduras from June 1996 to June 1997. Sites are labeled “riverine” or “embayment” depending on whether or not a river discharges directly into the estuary.

Variable	Mean	SD	Count	Minimum	Maximum	Median
GMSB 2 - RIVERINE						
Salinity (ppt)	18.3	13.1	32	0	37	18.8
Total Ammonia (mg l^{-1})	0.514	2.508	33	0.002	14.475	0.053
Total Nitrogen (mg l^{-1})	0.815	0.209	32	0.455	1.531	0.798
Nitrates + Nitrites (mg l^{-1})	0.333	0.177	32	0.067	0.807	0.36
Total Phosphorus (mg l^{-1})	0.166	0.041	32	0.076	0.277	0.16
React. Filter. Phosphate (mg l^{-1})	0.129	0.025	33	0.067	0.184	0.129
Total Alkalinity (mg l^{-1})	125.4	28.6	31	65.7	160.3	135.6
Chlorophyll *a* (mg l^{-1})	9.6	5.5	32	0	21.2	9.35
BOD_2 (mg l^{-1})	1.4	1.0	32	0.5	5.25	1.25
Settleable Solids (mg l^{-1})	0.2	0.5	32	0	2.3	0.05
GMSB 1 - RIVERINE						
Salinity (ppt)	17.9	11.7	31	0	33.5	19.0
Total Ammonia (mg l^{-1})	0.088	0.06	32	0.002	0.202	0.099
Total Nitrogen (mg l^{-1})	0.85	0.281	31	0.5	1.591	0.822
Nitrates + Nitrites (mg l^{-1})	0.299	0.149	32	0.008	0.566	0.318
Total Phosphorus (mg l^{-1})	0.147	0.047	31	0.036	0.289	0.15
React. Filter. Phosphate (mg l^{-1})	0.108	0.028	32	0.029	0.151	0.108
Total Alkalinity (mg l^{-1})	117.4	31.2	29	51	156.4	125.9
Chlorophyll *a* (mg l^{-1})	16.9	10.0	31	4.1	48.3	14.7
BOD_2 (mg l^{-1})	1.5	0.6	31	0.2	2.75	1.5
Settleable Solids (mg l^{-1})	1.4	1.8	31	0	8	0.5
SEA FARMS 1 - EMBAYMENT						
Salinity (ppt)	30.0	4.0	20	16.5	35.5	30.8
Total Ammonia (mg l^{-1})	0.036	0.04	21	0.003	0.131	0.016
Total Nitrogen (mg l^{-1})	0.272	0.087	21	0.15	0.436	0.263
Nitrates + Nitrites (mg l^{-1})	0.007	0.008	21	0	0.033	0.005
Total Phosphorus (mg l^{-1})	0.055	0.02	21	0.036	0.129	0.05
React. Filter. Phosphate (mg l^{-1})	0.033	0.023	21	0.003	0.104	0.025
Total Alkalinity (mg l^{-1})	114.9	8.5	19	97.3	127.7	115.4
Chlorophyll *a* (mg l^{-1})	4.4	3.7	20	0	15.9	4.25
BOD_2 (mg l^{-1})	1.2	0.6	21	0.4	3.45	1.15
Settleable Solids (mg l^{-1})	0	0	20	0	0	0

Table 1. Continued.

Variable	Mean	SD	Count	Minimum	Maximum	Median
SEA FARMS 2 - EMBAYMENT						
Salinity (ppt)	29.4	3.0	20	23	35.5	30.0
Total Ammonia (mg l^{-1})	0.034	0.035	21	0.001	0.132	0.03
Total Nitrogen (mg l^{-1})	0.278	0.062	21	0.163	0.355	0.299
Nitrates + Nitrites (mg l^{-1})	0.015	0.025	21	0	0.117	0.007
Total Phosphorus (mg l^{-1})	0.03	0.019	21	0.016	0.109	0.023
React. Filter. Phosphate (mg l^{-1})	0.009	0.009	21	0	0.039	0.01
Total Alkalinity (mg l^{-1})	110.3	8.3	20	92.6	120.8	113.7
Chlorophyll *a* (mg l^{-1})	3.3	1.7	20	0	6.6	2.9
BOD_2 (mg l^{-1})	1.5	1.1	21	0.65	5	1.1
Settleable Solids (mg l^{-1})	0	0	20	0	0	0
LA JAGUA - RIVERINE						
Salinity (ppt)	14.1	12.9	30	0	34	12.3
Total Ammonia (mg l^{-1})	0.084	0.06	31	0.001	0.24	0.084
Total Nitrogen (mg l^{-1})	0.952	0.237	30	0.578	1.493	0.901
Nitrates + Nitrites (mg l^{-1})	0.417	0.182	31	0.055	0.907	0.382
Total Phosphorus (mg l^{-1})	0.176	0.037	29	0.11	0.254	0.175
React. Filter. Phosphate (mg l^{-1})	0.128	0.028	30	0.079	0.219	0.127
Total Alkalinity (mg l^{-1})	123.7	38.7	29	49	171.7	146.7
Chlorophyll *a* (mg l^{-1})	20.7	13.9	31	2.4	61.6	17.7
BOD_2 (mg l^{-1})	2.5	1.5	30	0.85	7.5	2.075
Settleable Solids (mg l^{-1})	2.2	3.3	29	0.05	14	0.8
CRIMASA - RIVERINE						
Salinity (ppt)	23.2	15.0	23	1.5	47	29.0
Total Ammonia (mg l^{-1})	0.114	0.109	24	0	0.383	0.092
Total Nitrogen (mg l^{-1})	0.931	0.191	23	0.586	1.233	0.971
Nitrates + Nitrites (mg l^{-1})	0.26	0.198	24	0.005	0.641	0.207
Total Phosphorus (mg l^{-1})	0.187	0.051	23	0.116	0.29	0.175
React. Filter. Phosphate (mg l^{-1})	0.152	0.056	24	0.024	0.233	0.167
Total Alkalinity (mg l^{-1})	131.4	34.9	22	57.9	174.6	150.25
Chlorophyll *a* (mg l^{-1})	11.9	11.3	24	0	45.9	8.6
BOD_2 (mg l^{-1})	2.0	1.1	23	0.45	5.7	1.6
Settleable Solids (mg l^{-1})	0.8	1.0	22	0	3.5	0.4

Table 1. Continued.

Variable	Mean	SD	Count	Minimum	Maximum	Median
CONCHAL - EMBAYMENT						
Salinity (ppt)	28.8	3.7	31	21	34	29.0
Total Ammonia (mg l^{-1})	0.024	0.02	33	0	0.088	0.018
Total Nitrogen (mg l^{-1})	0.259	0.07	32	0.119	0.458	0.258
Nitrates + Nitrites (mg l^{-1})	0.01	0.009	33	0	0.036	0.008
Total Phosphorus (mg l^{-1})	0.035	0.013	31	0.016	0.07	0.03
React. Filter. Phosphate (mg l^{-1})	0.01	0.005	33	0	0.022	0.01
Total Alkalinity (mg l^{-1})	109.6	9.0	31	93.1	126.9	112.6
Chlorophyll *a* (mg l^{-1})	3.9	2.5	33	0	9.7	2.9
BOD_2 (mg l^{-1})	1.1	1.3	32	0.15	7.65	0.85
Settleable Solids (mg l^{-1})	0.01	0.02	30	0	0.05	0
CULCAMAR 2 - EMBAYMENT						
Salinity (ppt)	17.3	9.5	12	1	27	20.3
Total Ammonia (mg l^{-1})	0.109	0.111	13	0.005	0.36	0.066
Total Nitrogen (mg l^{-1})	0.497	0.135	12	0.257	0.676	0.499
Nitrates + Nitrites (mg l^{-1})	0.013	0.009	13	0	0.027	0.012
Total Phosphorus (mg l^{-1})	0.104	0.148	13	0.023	0.537	0.036
React. Filter. Phosphate (mg l^{-1})	0.094	0.165	13	0	0.478	0.011
Total Alkalinity (mg l^{-1})	105.5	19.7	12	64.7	132.7	101.6
Chlorophyll *a* (mg l^{-1})	9.8	6.7	13	4.3	29.4	7.2
BOD_2 (mg l^{-1})	1.1	0.8	12	0.3	2.6	0.75
Settleable Solids (mg l^{-1})	0.1	0.2	13	0	0.5	0.05
CADELPA LAS ARENAS - EMBAYMENT						
Salinity (ppt)	26.6	6.8	30	9	34	28.8
Total Ammonia (mg l^{-1})	0.029	0.033	31	0	0.176	0.023
Total Nitrogen (mg l^{-1})	0.289	0.099	30	0.106	0.504	0.284
Nitrates + Nitrites (mg l^{-1})	0.023	0.028	31	0	0.101	0.01
Total Phosphorus (mg l^{-1})	0.026	0.014	30	0.009	0.076	0.023
React. Filter. Phosphate (mg l^{-1})	0.006	0.008	30	0	0.035	0.003
Total Alkalinity (mg l^{-1})	104.6	14.9	29	58.9	122.8	107.6
Chlorophyll *a* (mg l^{-1})	3.5	1.7	31	0	7.5	2.9
BOD_2 (mg l^{-1})	0.8	0.4	30	0.1	2.25	0.8
Settleable Solids (mg l^{-1})	0.003	0.018	30	0	0.1	0

Table 1. Continued.

Variable	Mean	SD	Count	Minimum	Maximum	Median
CADELPA-TULITO 1 - RIVERINE						
Salinity (ppt)	13.6	13.6	32	0	39	6.3
Total Ammonia (mg l^{-1})	0.206	0.144	33	0.027	0.495	0.177
Total Nitrogen (mg l^{-1})	1.311	0.472	32	0.532	2.325	1.306
Nitrates + Nitrites (mg l^{-1})	0.225	0.226	33	0.002	0.784	0.098
Total Phosphorus (mg l^{-1})	0.21	0.054	32	0.089	0.307	0.218
React. Filter. Phosphate (mg l^{-1})	0.151	0.073	33	0	0.287	0.177
Total Alkalinity (mg l^{-1})	131.6	44.4	31	58.9	182.2	150.5
Chlorophyll *a* (mg l^{-1})	32.0	25.0	33	8.1	119.6	24.9
BOD_2 (mg l^{-1})	3.5	1.7	32	1.15	8.7	3.35
Settleable Solids (mg l^{-1})	0.6	0.7	31	0	3.5	0.3
CADEMA - EMBAYMENT						
Salinity (ppt)	27.5	5.3	33	15.5	34	29.5
Total Ammonia (mg l^{-1})	0.027	0.021	35	0	0.095	0.025
Total Nitrogen (mg l^{-1})	0.296	0.172	34	0.123	1.17	0.266
Nitrates + Nitrites (mg l^{-1})	0.024	0.027	35	0	0.12	0.012
Total Phosphorus (mg l^{-1})	0.03	0.013	34	0.016	0.076	0.024
React. Filter. Phosphate (mg l^{-1})	0.01	0.007	35	0	0.029	0.01
Total Alkalinity (mg l^{-1})	108.1	11.5	33	82.3	123.8	111.9
Chlorophyll *a* (mg l^{-1})	3.4	2.1	35	0	10	2.7
BOD_2 (mg l^{-1})	0.9	0.8	33	0.15	5.05	0.85
Settleable Solids (mg l^{-1})	0.05	0.14	34	0	0.7	0
BIOMAR - RIVERINE						
Salinity (ppt)	19.8	11.9	28	0.5	34.5	21.3
Total Ammonia (mg l^{-1})	0.063	0.061	29	0.001	0.199	0.032
Total Nitrogen (mg l^{-1})	0.61	0.192	29	0.267	1.129	0.644
Nitrates + Nitrites (mg l^{-1})	0.212	0.126	29	0.002	0.407	0.22
Total Phosphorus (mg l^{-1}))	0.137	0.064	29	0.063	0.379	0.116
React. Filter. Phosphate (mg l^{-1})	0.089	0.032	29	0.001	0.163	0.087
Total Alkalinity (mg l^{-1})	111.0	30.7	27	29.9	150.5	122.8
Chlorophyll *a* (mg l^{-1})	9.0	4.1	29	2.7	17.8	8.4
BOD_2 (mg l^{-1})	1.1	0.5	28	0.15	2.5	1.125
Settleable Solids (mg l^{-1})	0.25	0.27	28	0	1	0.1

Table 1. Continued.

Variable	Mean	SD	Count	Minimum	Maximum	Median
AQUACULTIVOS #2 - RIVERINE						
Salinity (ppt)	3.0	5.8	23	0	20.5	0.5
Total Ammonia (mg l^{-1})	0.069	0.086	24	0.011	0.301	0.035
Total Nitrogen (mg l^{-1})	0.585	0.259	24	0.237	1.264	0.526
Nitrates + Nitrites (mg l^{-1})	0.064	0.136	24	0	0.505	0.003
Total Phosphorus (mg l^{-1})	0.227	0.1	24	0.109	0.411	0.216
React. Filter. Phosphate (mg l^{-1})	0.19	0.074	24	0.039	0.317	0.208
Total Alkalinity (mg l^{-1})	155.3	34.7	23	88.2	217.5	161.9
Chlorophyll *a* (mg l^{-1})	27.0	31.9	24	4	165.4	19.05
BOD_2 (mg l^{-1})	2.7	1.4	24	0.05	5.1	2.85
Settleable Solids (mg l^{-1})	0.28	0.56	23	0	2.8	0.1
AQUACULTIVOS - RIVERINE						
Salinity (ppt)	14.1	13.2	34	0	34	12.0
Total Ammonia (mg l^{-1})	0.122	0.08	35	0.001	0.395	0.111
Total Nitrogen (mg l^{-1})	1.011	0.31	35	0.316	1.841	0.976
Nitrates + Nitrites (mg l^{-1})	0.353	0.149	35	0.033	0.782	0.345
Total Phosphorus (mg l^{-1})	0.169	0.053	35	0.09	0.363	0.163
React. Filter. Phosphate (mg l^{-1})	0.124	0.043	35	0.052	0.261	0.115
Total Alkalinity (mg l^{-1})	119.3	36.3	32	50.2	197	132.1
Chlorophyll *a* (mg l^{-1})	17.7	12.6	35	2.4	61.4	15.9
BOD_2 (mg l-1)	2.4	1.5	35	0.8	7.95	2.15
Settleable Solids (mg l^{-1})	1.9	3.2	34	0.05	16	0.7
AQUACULTURA FONSECA - RIVERINE						
Salinity (ppt)	11.8	12.1	27	0.5	37.5	5.0
Total Ammonia (mg l^{-1})	0.239	0.124	28	0.006	0.511	0.221
Total Nitrogen (mg l^{-1})	1.291	0.497	28	0.292	2.293	1.319
Nitrates + Nitrites (mg l^{-1})	0.307	0.243	28	0.015	0.787	0.253
Total Phosphorus (mg l^{-1})	0.19	0.062	28	0.07	0.331	0.19
React. Filter. Phosphate (mg l^{-1})	0.144	0.057	28	0.042	0.254	0.13
Total Alkalinity (mg l^{-1})	123.6	47.8	27	39.2	181.3	138.6
Chlorophyll *a* (mg l^{-1})	26.7	14.6	28	4.5	61.1	23.85
BOD_2 (mg l^{-1})	2.7	1.2	28	1	5	2.45
Settleable Solids (mg l^{-1})	1.6	2.6	27	0	12.8	0.6

Table 1. Continued.

Variable	Mean	SD	Count	Minimum	Maximum	Median
EL FARO - RIVERINE						
Salinity (ppt)	15.5	15.9	29	0	49	6.5
Total Ammonia (mg l^{-1})	0.2	0.135	30	0.016	0.6	0.196
Total Nitrogen (mg l^{-1})	1.042	0.357	29	0.25	1.974	1.056
Nitrates + Nitrites (mg l^{-1})	0.254	0.223	30	0	0.791	0.222
Total Phosphorus (mg l^{-1})	0.235	0.089	29	0.103	0.484	0.249
React. Filter. Phosphate (mg l^{-1})	0.198	0.075	30	0.076	0.424	0.205
Total Alkalinity (mg l^{-1})	140.8	49.0	27	43.1	223.2	163.8
Chlorophyll *a* (mg l^{-1})	11.4	12.0	30	0	55.5	7.65
BOD_2 (mg l^{-1})	2.1	1.2	28	0.8	6.3	2
Settleable Solids (mg l^{-1})	3.0	7.4	29	0	31	0.1
FINCASUR - RIVERINE						
Salinity (ppt)	2.0	2.2	12	0	6.5	1.5
Total Ammonia (mg l^{-1})	0.118	0.087	12	0.032	0.35	0.104
Total Nitrogen (mg l^{-1})	0.847	0.318	12	0.43	1.346	0.804
Nitrates + Nitrites (mg l^{-1})	0.091	0.138	12	0.003	0.373	0.019
Total Phosphorus (mg l^{-1})	0.216	0.072	12	0.103	0.379	0.199
React. Filter. Phosphate (mg l^{-1})	0.147	0.059	12	0.046	0.287	0.138
Total Alkalinity (mg l^{-1})	98.9	26.1	11	51.9	129.4	95.5
Chlorophyll *a* (mg l^{-1})	30.8	27.1	12	6	81.9	21.35
BOD_2 (mg l^{-1})	3.7	2.2	12	1.25	8.7	3.25
Settleable Solids (mg l^{-1})	2.3	6.3	12	0.05	22	0.25
ICASUR - RIVERINE						
Salinity (ppt)	16.8	12.8	16	0	32.5	18.3
Total Ammonia (mg l^{-1})	0.093	0.064	16	0.002	0.18	0.074
Total Nitrogen (mg l^{-1})	0.469	0.274	15	0.208	1.289	0.422
Nitrates + Nitrites (mg l^{-1})	0.075	0.06	16	0	0.189	0.07
Total Phosphorus (mg l^{-1})	0.082	0.04	15	0.036	0.182	0.076
React. Filter. Phosphate (mg l^{-1})	0.042	0.022	16	0.017	0.097	0.039
Total Alkalinity (mg l^{-1})	116.8	37.9	15	41.5	170.8	124.5
Chlorophyll *a* (mg l^{-1})	5.3	3.3	16	0	13.1	4.6
BOD_2 (mg l^{-1})	1.7	2.2	14	0.15	8.95	1
Settleable Solids (mg l^{-1})	0	0	3	0	0	0

Table 1. Continued.

Variable	Mean	SD	Count	Minimum	Maximum	Median
CHOLUTECA RIVER AT LA LUJOSA						
Salinity (ppt)	0	0	36	0	0	0
Total Ammonia (mg l^{-1})	0.044	0.069	37	0	0.401	0.025
Total Nitrogen (mg l^{-1})	0.726	0.368	36	0.311	2.534	0.704
Nitrates + Nitrites (mg l^{-1})	0.242	0.297	37	0	1.35	0.137
Total Phosphorus (mg l^{-1})	0.251	0.125	36	0.103	0.598	0.229
React. Filter. Phosphate (mg l^{-1})	0.194	0.093	37	0.015	0.365	0.184
Total Alkalinity (mg l^{-1})	119.1	38.0	35	49	166	137.6
Chlorophyll *a* (mg l^{-1})	25.5	20.8	36	1.9	77.9	23.9
BOD_2 (mg l^{-1})	2.4	1.6	35	0.3	8.25	2.2
Settleable Solids (mg l^{-1})	0.23	0.41	36	0	1.8	0.05

Discussion

Cyclical trends for short-term enrichment in riverine estuaries are related to season. Regular rains flush estuaries and reduce the danger of long-term eutrophication. However, the particularly high concentrations of nitrogen and phosphorus observed during the summer of 1994 illustrate that short-term nutrient enrichment can reach possibly dangerous levels. Tardy rains and inordinately high nutrient discharge from shrimp farms could result in water quality conditions that are not conducive to shrimp growth. Producers located upstream in the estuaries are particularly vulnerable to poor water quality, because estuarine exchange with the gulf decreases rapidly with distance upstream (Teichert-Coddington, 1995).

Shrimp growth is coincidentally slow during the summers, probably because of cooler temperatures (Teichert-Coddington et al., 1994), and feeding should be reduced accordingly. Some smaller farms close during the summer months because of slow shrimp growth. Dry season water quality is currently manageable in most riverine estuaries, but increased expansion of farms or increased stocking densities on existing farms could cause eutrophication of these estuaries.

Embayment water quality is much more stable during the year because it is not as drastically affected by rainfall and has a higher capacity for assimilation of discharged nutrients. Salinities fall during the wet season with increased river discharge, but the fluctuations are moderated by the larger body of gulf water. A high tidal range (1.5 to 3.5 m) which promotes water exchange and nutrient dilution with the Pacific Ocean affects the Gulf of Fonseca—gulf water is less fertile than riverine water. Spikes in nutrient concentration occur in small embayments probably during periods of low tides. Nutrients may remain concentrated until a good tidal exchange replaces the embayment water.

Anticipated Benefits

The estuarine water quality database serves to track long-term changes in water quality in estuaries of the shrimp-producing region of southern Honduras. These data will be used in the development of carrying capacity models for the individual estuaries. Carrying capacity models will provide quantitative information to decision makers in the Government of Honduras and in the Honduran Association of Aquaculturists to allow them to formulate strategies and regulations regarding future shrimp industry development.

Acknowledgments

We appreciate Jaime Lopez's assistance in the laboratory. This study was made possible by collaboration of the Dirección General de Pesca y Acuicultura, Secretaría de Agricultura y Ganadería, República de Honduras, and shrimp producers of the Honduran National Association of Aquaculturists (ANDAH).

Literature Cited

American Public Health Association (APHA), 1985. Standard Methods for the Examination of Water and Wastewater. American Public Health Association, Washington DC, 1268 pp.

Grasshoff, K., M. Ehrhardt, and K. Kremling (Editors), 1983. Methods of Seawater Analysis. Verlag Chemie, Weinheim, 419 pp.

Green, B.W., D.R. Teichert-Coddington, G.H. Ward, and C.E. Boyd, 1997. Collaborative research to support sustainable shrimp culture in Honduras: a model program. In: Book of Abstracts, World Aquaculture '97, February 19-23, 1997, Seattle, Washington. World Aquaculture Society, Baton Rouge, Louisiana, USA, pp. 186-187.

Parsons, T.R., Y. Maita, and C.M. Lalli, 1992. A Manual of Chemical and Biological Methods for Seawater Analysis. Pergamon Press, New York, 173 pp.

Teichert-Coddington, D.R., R. Rodriguez, and W. Toyofuku, 1994. Causes of cyclical variation in Honduran shrimp production. World Aquaculture, 25(1):57-61.

Teichert-Coddington, D.R., 1995. Estuarine water quality and sustainable shrimp culture in Honduras. In: C.L. Browdy and J.S. Hopkins (Editors), Swimming Through Troubled Water. Proceedings of the Special Session on Shrimp Farming, Aquaculture '95. World Aquaculture Society, Baton Rouge, Louisiana, USA, pp. 144-155.